

Jet Propulsion Laboratory
California Institute of Technology

HabEx Architecture Option A Overview

STDT Meeting #6

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Wednesday, May 2, 2018

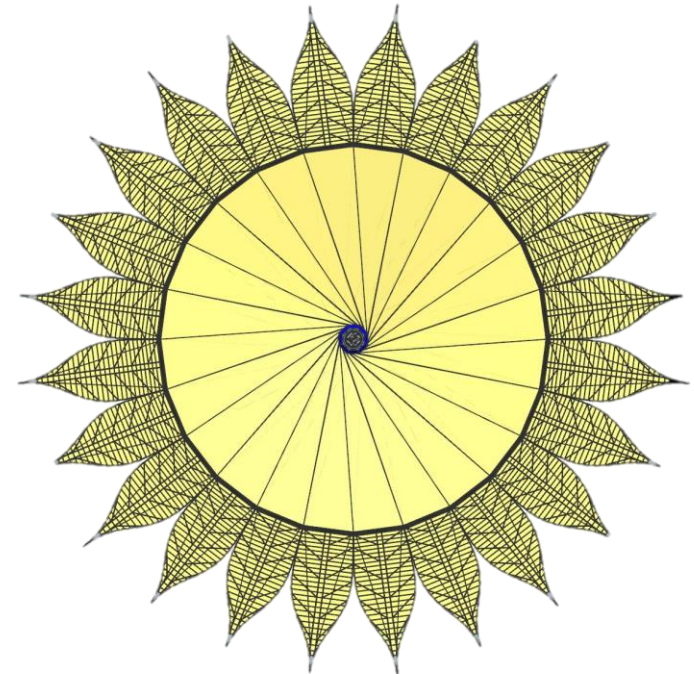
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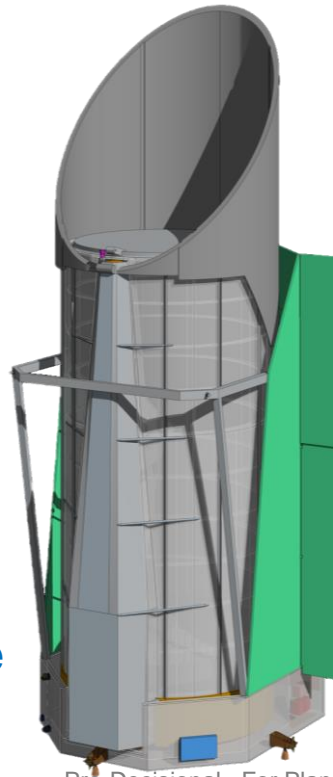


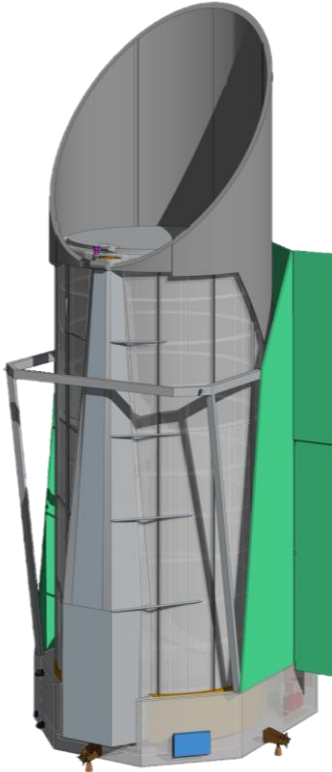
- Summary of Architecture Option A
- Key Design Features and Rationale
 - Vector Vortex Coronagraph
 - 72-m Starshade
 - Microthrusters

72-meter diameter Starshade

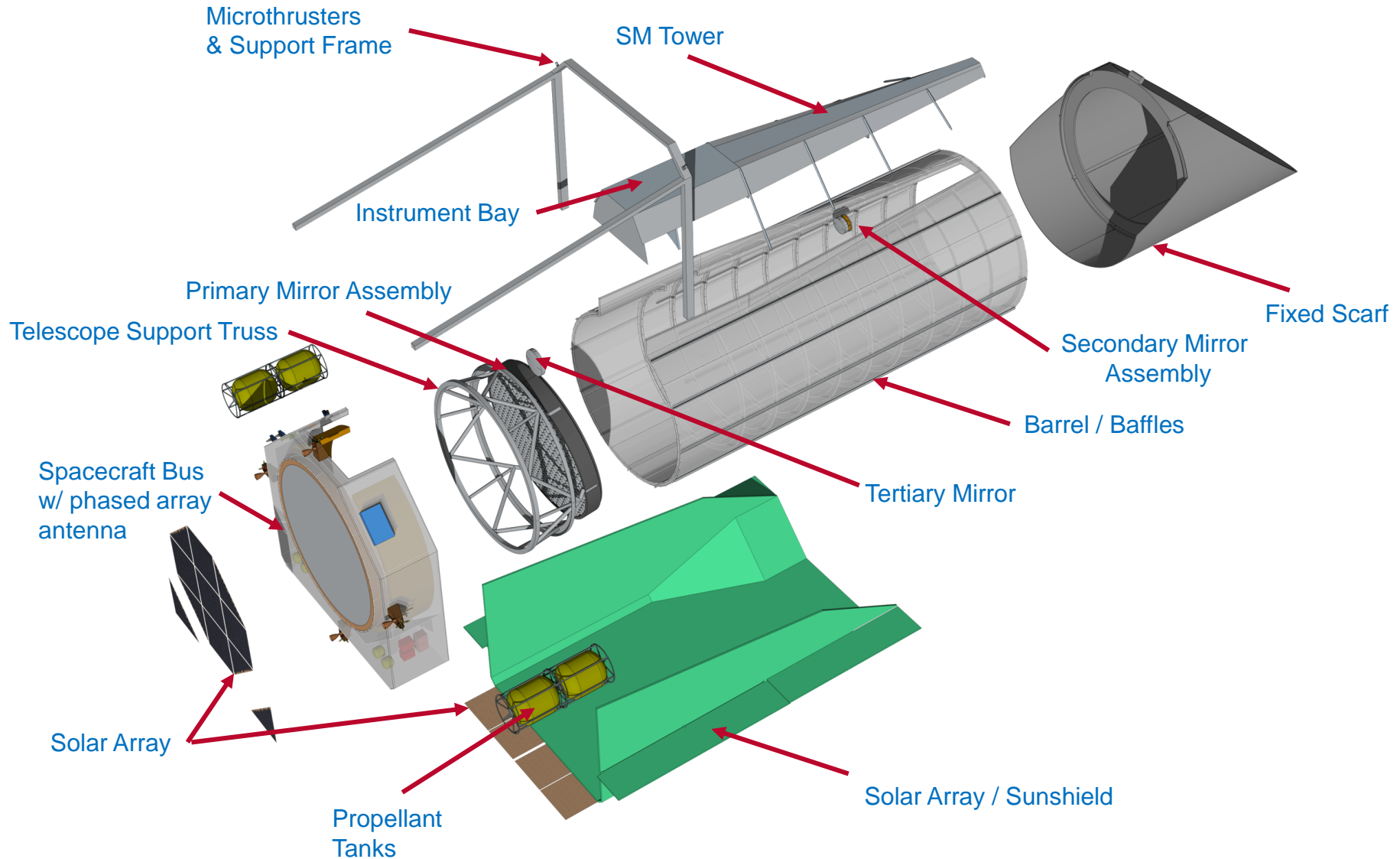


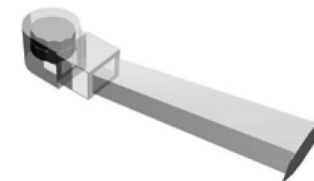
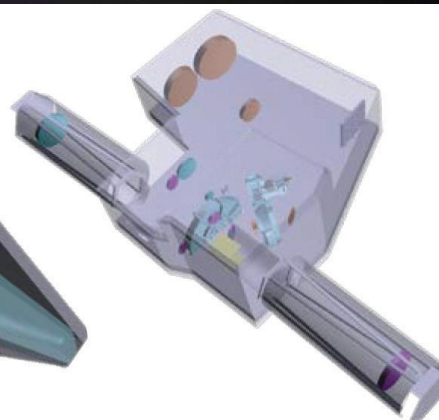
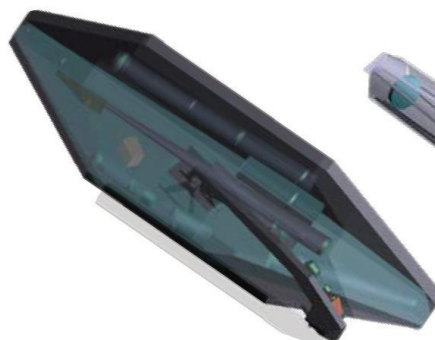
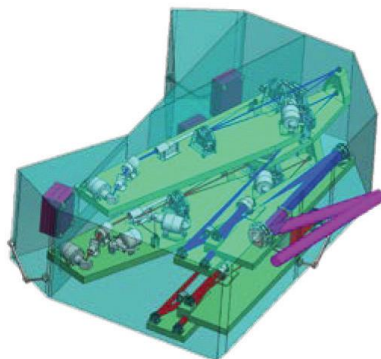
4-meter diameter
aperture Telescope





- 4-meter diameter aperture
- Off-axis, Three-mirror anastigmat telescope (unobscured)
- Four Instruments:
 - Coronagraph Imager/Spectrograph (CG)
 - Starshade Imager/Spectrograph (SS)
 - UV Spectrograph (UVS)
 - Workhorse Camera Imager/Spectrograph (HWC)
- Fine Guider Sensor (FGS)
- ACS Thrusters
- Microthrusters
- Solar Array/Sunshield
- Phased Array Antenna
 - Ka-band data downlink, 6.5Mbps
 - S-band cross-communications with Starshade





	Coronagraph	Starshade	Workhorse Camera	UV Spectrograph
Purpose	Exoplanet imaging and characterization	Exoplanet imaging and characterization	Multipurpose, wide-field imaging camera and spectrograph for general astrophysics	High-resolution, UV spectroscopy for general astrophysics
Instrument Type	Vortex charge 6 coronagraph with: <ul style="list-style-type: none"> - Raw contrast: 1×10^{-10} at IWA - Δmag limit = 26.0 - 20% instantaneous bandwidth Imager and spectrograph	72 m dia starshade occulter with: <ul style="list-style-type: none"> - 124,000 km separation - Raw contrast: 1×10^{-10} at IWA - Δmag limit = 26.0 - 107% instantaneous bandwidth Imager and spectrograph	Imager and spectrograph	High-resolution spectrograph
Channels	Vis, Blue: 0.45–0.67 μm Imager + IFS with R = 140 Vis, Red: 0.67–1.0 μm Imager + IFS with R = 140 NIR: 0.95–1.8 μm , Imager + slit spectrograph with R = 40	UV: 0.2–0.45 μm Imager + grism with R = 7 Vis: 0.45–1.0 μm Imager + IFS with R = 140 NIR: 0.95–1.8 μm Imager + IFS with R = 40	UV: 0.15–0.4 μm Imager + grism with R = 2,000 Vis: 0.4–0.95 μm Imager + grism with R = 2,000 NIR: 0.95–1.8 μm Imager + grism with R = 2,000	UV: 0.115–0.3 μm (20 bands), R = 60,000; 25,000; 12,000; 6,000; 3,000; 1,000; 500
Field of View	FOV: $1.5 \times 1.5 \text{ arcsec}^2$ @ 0.5 μm IWA: $2.4 \lambda/D = 62 \text{ mas}$ @ 0.5 μm OWA: 0.74 arcsec @ 0.5 μm	FOV: $11.9 \times 11.9 \text{ arcsec}^2$ (Vis) IWA: 60 mas (0.3–1.0 μm) OWA: 6 arcsec (Vis)	$3 \times 3 \text{ arcmin}^2$	$3 \times 3 \text{ arcmin}^2$
Features	64x64 deformable mirrors (2) Low-order wavefront sensing & control	Formation flying sensing & control	Microshutter array for multi-object spectroscopy 2x2 array, 171x365 apertures	Microshutter array for multi-object spectroscopy 2x2 array, 171x365 apertures



72-meter diameter (tip-to-tip)

40-meter diameter central disk

16-meter petals (x22)

Solar Electric Propulsion (SEP) Hall Effect thrusters

2 flight + 1 spare, each side (6 total)

Bi-prop hydrazine thrusters

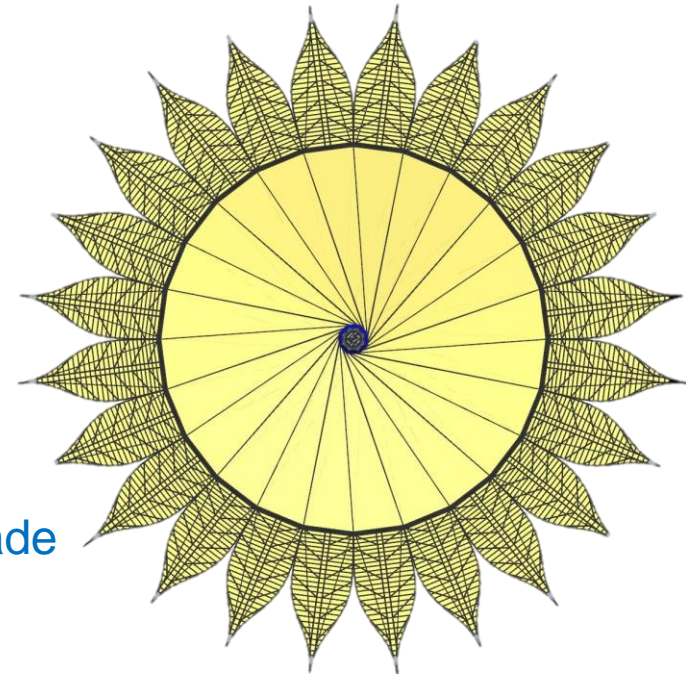
ACS

Orbit maintenance

Communications

X-band to ground, 1kbps, command & ranging

S-band to telescope, 100bps, data transfer & ranging



72-meter diameter Starshade



- 72m diameter Starshade deploys radially from Hub exterior

- PLUS (Petal Launch Restraint & Unfurler Subsystem)
 - deploys the Starshade occulter (jettisoned after use)

- Starshade Bus fits within the Starshade Hub

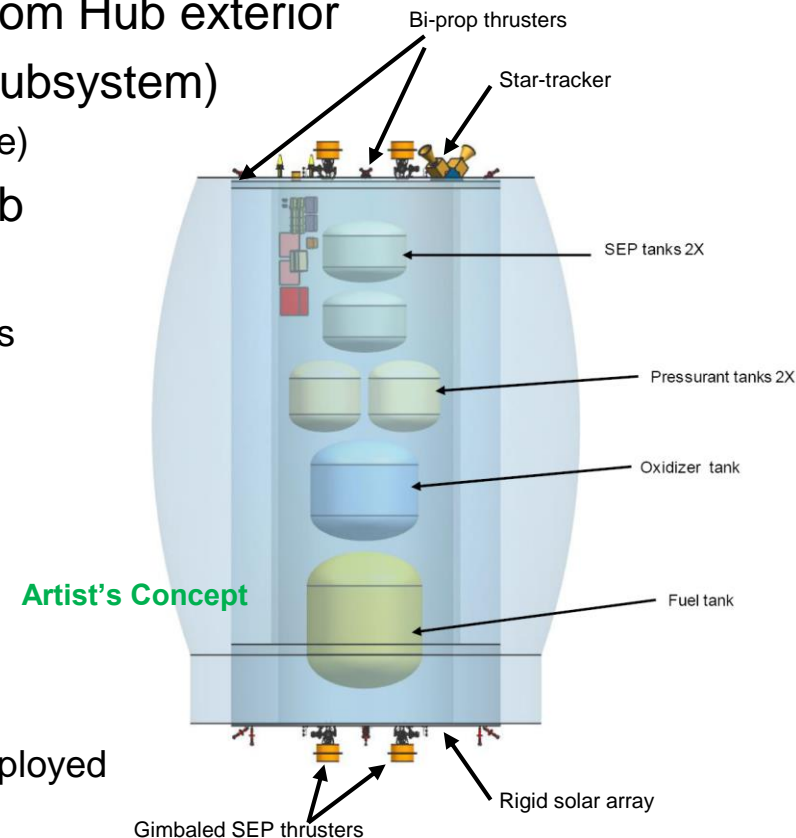
- Starshade Bus fits within the Starshade Hub

- Bus Includes:

- Solar Electric Propulsion (SEP) Hall effect thrusters
 - 2 Flight / 1 Spare (on each end)
- Bi-prop chemical thrusters
- Communications, with ground & telescope
- Formation Flying beacon
- Electronics
- Solar Array (2 sets)
 - 1 rigid array on end of hub
 - 1 flexible CIGS array starshade disc when deployed
- Thermal Control

- Starshade is spin-stabilized at 0.33 RPM
 - allows starshade occulter temperature to be passively controlled

- Communications same as telescope (w/o extra 1Tb storage)

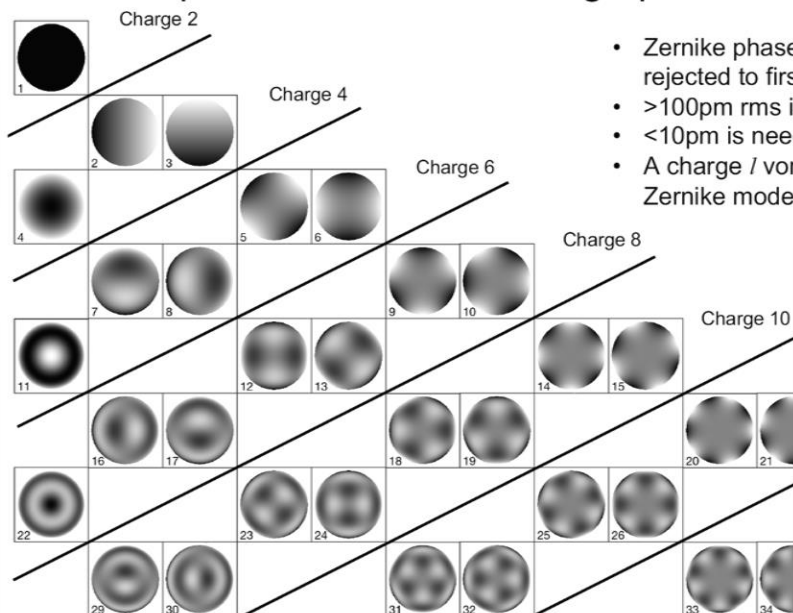




- Purpose:
 - to maximize planet light throughput and contrast and minimize requirements on the telescope
- Rationale:
 - Vector Vortex Coronagraphs exhibit very good performance on par (theoretically) with HLC or other coronagraph types
 - Have been demonstrated in the lab and on ground-based telescopes (though not to the level required for space)
 - VVCs are more forgiving on the telescope wavefront error stability by rejecting much of the lowest order Zernike WFE terms. These lowest terms are directly related to rigid body stability of the telescope optics as well as thermal bending modes.



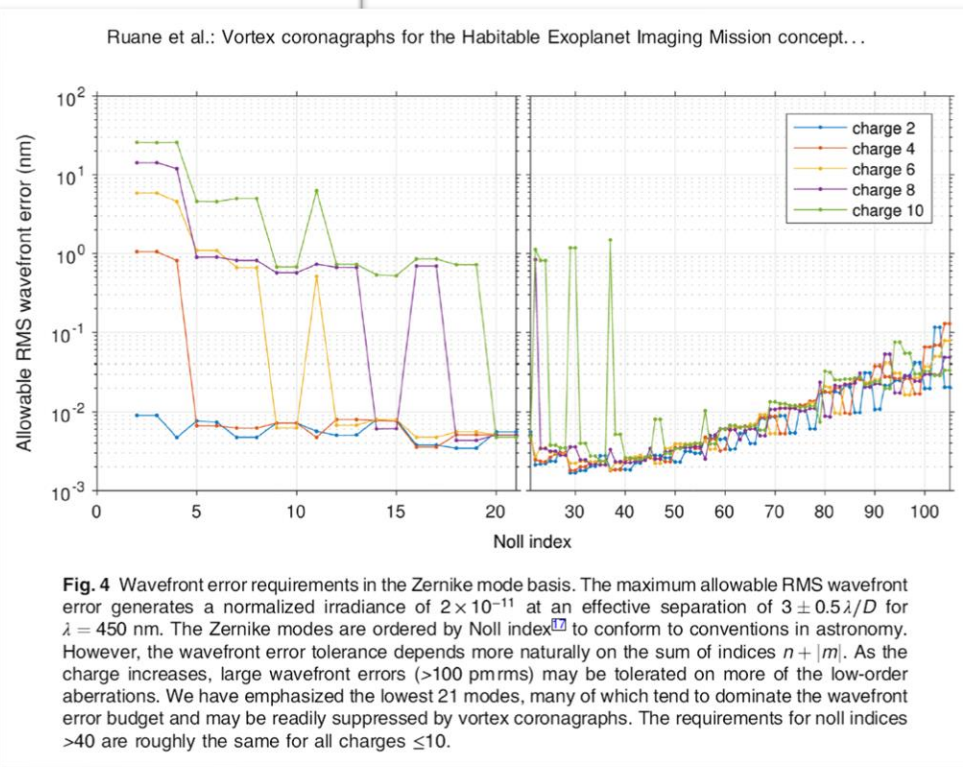
The null space of a vortex coronagraph



- Zernike phase aberrations above the line are rejected to first order.
- $>100\text{pm}$ rms is tolerable for null space modes.
- $<10\text{pm}$ is needed for other modes up to $\sim Z_{70}$.
- A charge l vortex coronagraph has $(l/2)^2$ Zernike modes in its null space.

Garreth Ruane, Dimitri Mawet, Bertrand Mennesson, Jeffrey B. Jewell, Stuart B. Shaklan, "Vortex coronagraphs for the Habitable Exoplanet Imaging Mission concept: theoretical performance and telescope requirements," *Journal of Astronomical Telescopes, Instruments, and Systems* 4(1), 015004 (28 March 2018). <https://doi.org/10.1117/1.JATIS.4.1.015004>
Submission: Received 14 November 2017; Accepted 9 March 2018

	Zern Mode	M1 (pm rms)	M2 (pm rms)	M3 (pm rms)
focus	z4	2000.0	500.0	500.0
astig	z5	200.0	100.0	100.0
astig	z6	200.0	100.0	100.0
coma	z7	150.0	100.0	100.0
coma	z8	150.0	100.0	100.0
trefoil	z9	2.4	1.0	0.5
trefoil	z10	0.2	0.2	0.2
spherical	z11	100.0	100.0	100.0
2 astig	z12	0.2	0.2	0.2
2 astig	z13	0.2	0.2	0.2
quadrafoil	z14	0.2	0.2	0.2
quadrafoil	z15	0.2	0.2	0.2
2 coma	z16	0.2	0.2	0.2
2 coma	z17	0.2	0.2	0.2

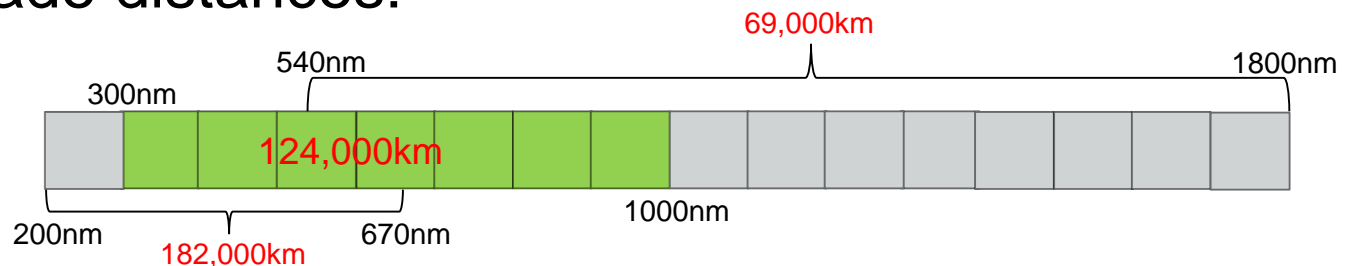


Example telescope optics
WFE stability allocations

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- Starshade IWA selected to match coronagraph at 500nm
 - $IWA = 2.4\lambda/D = 62\text{mas}$
- Starshade diameter requirements:
 - 300nm – 1000nm at a single distance
 - $IWA = 60\text{mas}$ at the tip (+margin)
 - Fresnel #10.5
- Starshade dimensions:
 - 40m diameter central disk
 - 16m long petals (quantity: 22)
- Starshade distances:

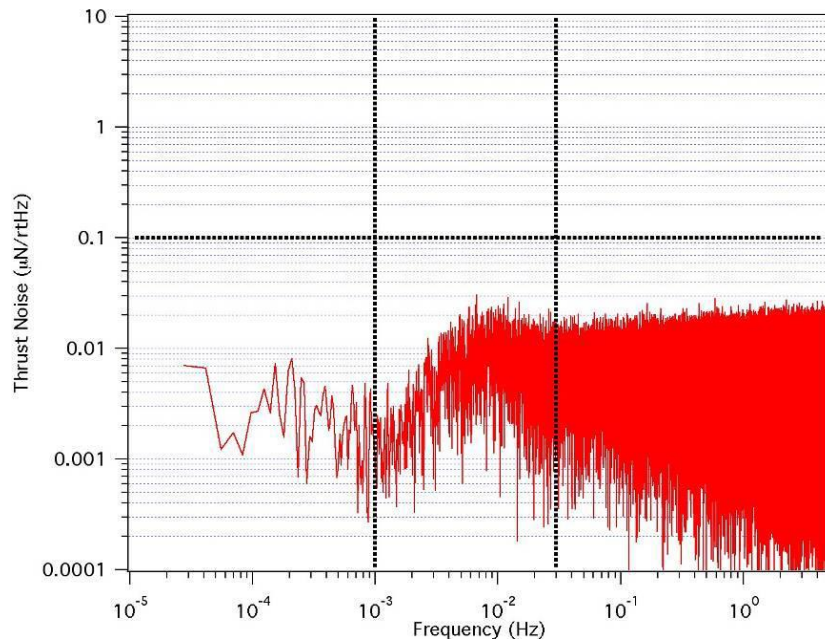




- Purpose:
 - to offset solar pressure which imparts torque on the telescope.
- Background:
 - Solar pressure is $0.5\mu\text{N}/\text{m}^2$ at Sun-Earth L2.
 - HabEx has $\sim 100\text{m}^2$ projected area,
 - Solar pressure is $\sim 50\mu\text{N}$, with about a 3-4m offset from the center of mass.
- Rationale:
 - Microthrusters have sufficient thrust (single thruster $\leq 30\mu\text{N}$ on ST7)
 - Has very good thrust resolution ($\leq 0.1\mu\text{N}$)
 - Likely higher reliability than reaction wheels (to be tested to confirm, but reaction wheels have had high profile failures)
 - Likely significantly less noise than reaction wheels ($\leq 0.03\mu\text{N}/\text{rtHz}$ over all frequencies) See next slide.



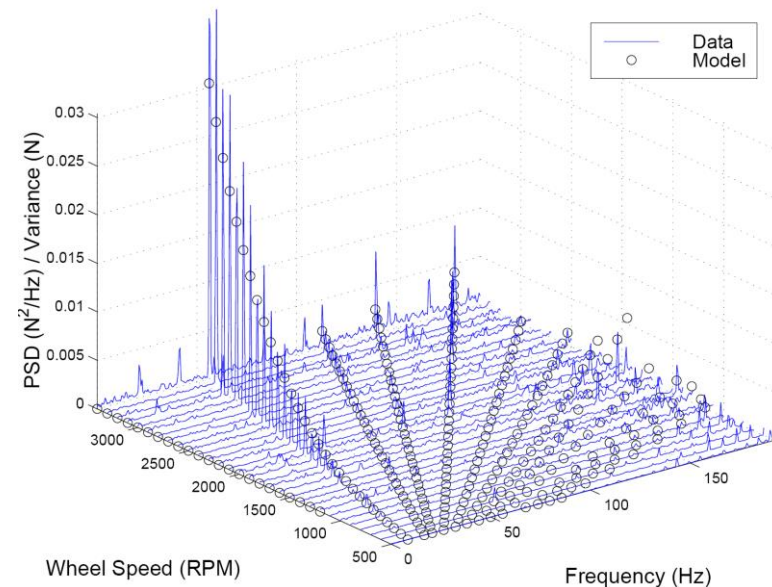
Units: $\mu\text{N}/\text{rtHz}$



Thruster noise PSD plot for colloidal microthrusters. Max noise above 10^{-3} is likely due to thrust-balance sensor noise limits.

(ref: *"Colloid Micro-Newton Thrusters For Precision Attitude Control"*, John Ziemer, et. al, April 2017, CL#17-2067)

Units: N^2/Hz



Waterfall plot derived from measured data showing Ithaco B-wheel Fx data and the radial force model
(reference: *"Conditioning, Reduction, and Disturbance Analysis of Large Order Integrated Models for Space-Based Telescopes"* By Scott Alan Uebelhart, MIT 2001)



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